

CLAIMS

1. A rectal probe adapted for ultrasound and magnetic resonance imaging of the prostate, comprising:

5 a) an ultrasound imaging probe;

b) an MRI probe comprising a first magnetic field source for creating a static magnetic field in an MRI imaging region outside the rectal probe, a second magnetic field source for creating a time-varying magnetic field which excites nuclei in the MRI imaging region, and a receiver for receiving NMR signals from the excited nuclei and generating MRI
10 imaging data indicative thereof; and

c) a link joining the ultrasound probe and the MRI probe.

2. A rectal probe according to claim 1, wherein the link is flexible, thereby allowing a direction of orientation of the MRI probe to vary relative to a direction of orientation of the
15 ultrasound probe.

3. A rectal probe according to claim 1, wherein the MRI probe has a longitudinal axis, and the static magnetic field is substantially inhomogeneous, defined as monotonically decreasing with
20 increasing distance from the longitudinal axis, outside the MRI probe, in all directions.

4. A rectal probe according to any of claims 1-3, wherein the first magnetic field source is a permanent magnet, and the magnetic field is at least 0.35 tesla at at least one point on the surface of the MRI probe.

25 5. A rectal probe according to any of claims 1-3, wherein the first magnetic field source is a permanent magnet, and the magnetic field is at least 0.01 tesla at at least one point at a distance 50 mm from the surface of the MRI probe.

30 6. A rectal probe according to any of claims 1-3, wherein the first magnetic field source is a permanent magnet, and the magnetic field has a gradient of at least about one tesla per meter, at at least one point 50 mm from the surface of the MRI probe.

7. A rectal probe according to any of claims 1-3, wherein the second magnetic field source is a coil which produces a magnetic field of at least 4 micro-tesla per ampere of current, at at least one point at a distance 50 mm from the surface of the probe.

5 8. An imaging system comprising:

a) a rectal probe according to any of claims 1-3; and

b) an RF power supply which supplies power to the second magnetic field source;

wherein the RF power supply is capable of supplying the second magnetic field source with sufficient power at a great enough frequency range to simultaneously excite nuclei in the imaging
10 region to generate NMR signals having a frequency bandwidth of more than 5% of their mean frequency, and wherein the static magnetic field monotonically decreases with increasing radial distance from the outer surface of the MRI probe, everywhere outside the outer surface of the MRI probe.

15 9. An imaging system according to claim 8, wherein the NMR signals have a frequency bandwidth of more than 10% of their mean frequency.

10. An imaging system according to claim 9, wherein the NMR signals have a frequency bandwidth of more than 20% of their mean frequency.

20 11. An imaging system comprising:

a) a rectal probe according to any of claims 1-3; and

b) an RF power supply which supplies a given power to the second magnetic field source;

wherein the MRI probe, when supplied with said given power by the RF power supply, is capable
25 of producing MRI imaging data with sufficient spatial resolution and signal to noise ratio to be capable of revealing a tumor 5 mm in diameter located anywhere in the prostate.

12. An imaging system comprising:

a) a rectal probe according to any of claims 1-3; and

30 b) an RF power supply which supplies a given power to the second magnetic field source;

wherein the second magnetic field source, when supplied with said given power by the RF power supply, is capable of creating a time varying magnetic field of at least 0.0025 tesla at at least one point at a distance of 50 mm from the surface of the MRI probe.

13. An imaging system comprising:

- a) a rectal probe according to any of claims 1-3;
- b) an RF power supply which supplies power to the second magnetic field source; and
- 5 c) a controller which controls the RF power supply to produce a timed sequence of RF pulses;

wherein the controller is adapted to control the RF power supply to produce the sequence of RF pulses with a repetition rate greater than one pulse every 0.5 milliseconds and less than one pulse every 0.25 milliseconds, and the RF power supply is capable of producing the sequence of RF
10 pulses at said repetition rate.

14. An imaging system comprising:

- a) a rectal probe according to any of claims 1-3, with a longitudinal axis, also including at least one gradient coil which produces a magnetic field gradient in the direction of the
15 longitudinal axis, or in an azimuthal direction around the longitudinal axis;
- b) a gradient coil power supply which supplies current to the gradient coil; and
- c) a controller which controls the gradient coil power supply to produce a timed sequence of gradient pulses;

wherein the controller is adapted to make the gradient pulses at least about 0.2 milliseconds long.
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15. A method of imaging the prostate, the method comprising:

- a) inserting a rectal probe according to claim 1 into a rectum;
- b) acquiring at least one ultrasound image of the prostate, using the ultrasound probe;
- c) acquiring MRI imaging data of the prostate using the MRI probe; and
- 25 d) reconstructing an image of the prostate from the MRI imaging data, using an image reconstruction procedure;

wherein an adjustment is made to one or both of the MRI probe and the image reconstruction procedure using information from the ultrasound image.

30 16. A method according to claim 15, wherein the adjustment causes the MRI imaging region to correspond more closely to the prostate or to a desired portion of the prostate.

17. A method according to claim 15, wherein the at least one ultrasound image comprises a plurality of ultrasound images acquired at different times between the beginning and end of acquisition of the MRI image, and the adjustment corrects for motion of the prostate occurring between the beginning and end of acquisition of the MRI image.

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18. A method according to claim 15, wherein the information from the ultrasound image comprises a Doppler shift, and the adjustment corrects for motion of the prostate occurring during acquisition of the MRI image.

- 10 19. A method of diagnosing the stage of prostate cancer, comprising:
- a) inserting a rectal probe according to claim 1 into a rectum;
 - b) acquiring an ultrasound image of the prostate using the ultrasound probe;
 - c) acquiring an MRI image of the prostate using the MRI probe;
 - d) finding prostate cancer on the MRI image; and
 - 15 e) examining the ultrasound image to determine whether or not the prostatic capsule is intact in the vicinity of the prostate cancer found on the MRI image.

20. A method according to claim 19, wherein acquiring an MRI image comprises acquiring a diffusion-weighted MRI image.

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21. A method of performing one or both of a biopsy and therapy on the prostate, comprising:
- a) inserting a rectal probe according to claim 1 into a rectum;
 - b) acquiring at least one ultrasound image of the prostate, using the ultrasound probe;
 - c) acquiring MRI imaging data of the prostate using the MRI probe;
 - 25 d) reconstructing an MRI image of the prostate from the MRI imaging data, using an image reconstruction procedure; and
 - e) performing one or both of a biopsy and therapy on the prostate, guided in real time by the ultrasound image and the MRI image.

- 30 22. A method of diagnosing prostate cancer, comprising:
- a) inserting into the rectum an MRI probe with a longitudinal axis, the MRI probe comprising a first magnetic field source for creating a substantially inhomogeneous static magnetic field in an MRI imaging region outside the probe, a second magnetic field source for

creating a time-varying magnetic field which excites nuclei in an extended sub-region of the MRI imaging region, and a receiver for receiving the NMR signals from the excited nuclei and generating MRI imaging data indicative thereof;

b) acquiring a diffusion-weighted MRI image of the prostate using the MRI probe; and

c) finding prostate cancer on the MRI image by using the difference in diffusion rate between cancerous and healthy tissue.

23. An imaging system comprising:

a) an MRI rectal probe adapted for imaging of the prostate, the probe having a longitudinal axis and comprising a first magnetic field source for creating a static magnetic field in an MRI imaging region outside the probe, a second magnetic field source for creating a time-varying magnetic field which excites nuclei in the MRI imaging region, and a receiver for receiving NMR signals from the excited nuclei and generating MRI imaging data indicative thereof; and

b) an RF power supply which supplies power to the second magnetic field source;

wherein the RF power supply is capable of supplying the second magnetic field source with sufficient power at a great enough frequency range to simultaneously excite nuclei in the imaging region to generate NMR signals having a frequency bandwidth of more than 5% of their mean frequency, and wherein the static magnetic field monotonically decreases with increasing radial distance from the longitudinal axis, everywhere outside the probe.

24. An MRI probe having a longitudinal axis, the probe comprising:

a) a first magnetic field source for creating a static magnetic field in an MRI imaging region outside the probe, which static magnetic field monotonically decreases with increasing distance from the longitudinal axis to the probe, everywhere outside the probe;

b) a second magnetic field source for creating a time-varying magnetic field which excites nuclei in the MRI imaging region;

c) a receiver for receiving the NMR signals from the excited nuclei and generating MRI imaging data thereof; and

d) at least one z gradient coil which produces a magnetic field gradient in the direction of the longitudinal axis.

25. A probe according to claim 24, of a size suitable for use as a rectal probe for imaging the prostate.